Bridging versus Bonding Social Capital and the Governance of Common Pool Resources[*†]

Job Market Paper

(October 2011)

Shun Wang

Department of Economics

University of British Columbia

Abstract: We compare the effect of bridging versus bonding social capital on the management of a common pool resource in this paper. We first develop a theoretical model and show that bonding social capital increases vulnerability to social sanction, while by giving communities an outside option, bridging social capital can reduce people's vulnerability, making them less susceptible to social sanction, and reducing the enforcement capability of the community. We then test this finding using household level data on firewood collection and social capital from the Yunnan province in China. We find that bonding social capital improves management of the common pool resource, but that the effect of bridging social capital is mixed. When bonding social capital is low, bridging social capital decreases the amount of resource consumption, however when bonding is high, bridging erode the effect of bonding. We also find that individuals with higher bridging social capital are less sensitive to the resource capacity, and those with few assets therefore few options to self-insure against risk, decrease their consumption with higher bridging social capital.

---

[*] This paper is a joint work with Kathy Baylis and Yazhen Gong.

[†] Department of Economics, University of British Columbia, 997 - 1873 East Mall, Vancouver, BC, V6T 1Z1, Canada (email: swangubc@hotmail.com).

1 Introduction

As in many developing regions, firewood is the primary source of fuel for heating and cooking in the Yunnan province of China, and demand for firewood has caused deforestation. The mountains in Yunnan have been deemed a "biological hotspot" by Conservation International, and firewood collection, along with illegal logging, has destroyed habitat for endangered species, such as the red panda (Conservation International, 2007; Xu and Wilkes, 2004). Because much rural land is held collectively, village forests are common pool resources (CPR), where it is difficult, if not impossible, to exclude use, and overconsumption is common. A number of authors have suggested that, with sufficient social capital, village-level management of CPRs can be successful, since village members can better detect over-use of the resource and often can enforce consumption rules more effectively. Because social capital can aid information flow and enforcement, it can help communities overcome the tragedy of the commons often associated with common pool resources (Acheson, 2000; Bowles and Gintis, 2002; Hardin, 1968; Meinzen-Dick *et al*., 2002; Ostrom, 1990, 1999). In this paper, we consider how social capital affects firewood collection in Yunnan.

There is a growing literature on the effect of social capital on economic growth, public good provision and management of CPRs (for a good review, see Durlauf and Fafchamps, 2005). Social capital, as measured by networks among communities has been shown to improve economic growth and opportunities (Algan and Cahuc, 2010; Fafchamps and Minten, 2002; Palloni *et al*., 2001; Narayan, 1999; Woolcock, 1998). This type of social capital is often referred to as "bridging" social capital (Putnam, 2000). Other studies have shown that ethnic homogeneity (Costa and Kahn, 2003; Easterly and Levine, 1997), increased vulnerability to social sanction (Anderson *et al*., 2009) and higher levels of trust (Helliwell, 1996; Knack and Keefer, 1997; La Porta *et al*., 1997) can increase growth, public good provision and improve co-management of CPRs. However, how the two types of social capital affect the management of a CPR is not clear. In this paper, we develop a model that compares the effect of bridging versus bonding social capital on the management of a CPR. We find that bonding social capital, by increasing the benefits of community, and therefore the cost of social sanction, always improves the community's ability to manage their CPR. By contrast, by giving communities an outside option, bridging social capital can reduce people's vulnerability, making them less susceptible to social sanction, and reducing the enforcement capability of the community. However, bridging social capital can also reduce the stress of the CPR for those people near the subsistence level. Therefore, we find the effect of bonding social capital to be clearly positive in terms of CPR management, while the effect of bridging social capital is mixed[1].

We test our theoretical results using a survey data and a field experiment from the province of Yunnan. Yunnan is of particular interest because its great biological diversity is threatened by firewood collection, and because it is ethnically diverse. Therefore, there is reason to believe that the level of social capital might vary from village to village. We collect data from 20 randomly-selected households in 30 villages in rural Yunnan. Specifically, we interview households on the amount of firewood collected on common land, the quality and use of private land, income, expenditure and their level of trust. To measure bonding social capital, we engage villagers in a field experiment, where villagers are given money and told that any funds sent to an anonymous other village member will be doubled, and that the recipient has the ability to return any portion of the financial gift to the sender.

We use the percent of days household members spend outside the township as an indicator of bridging social capital. The idea is that the more time a household member spends outside the region, greater the connection with the outside world, and therefore the greater the potential insurance against village-specific shocks. One might be concerned that this variable could affect firewood demand simply by reducing the cooking requirements of the household. To control for this concern, we include the number of household members living at home in the regression for firewood. As alternative measures for bridging social capital, we also use the number of household members working outside the township, the percent of members working outside the township, and the percent of days worked outside the county, and all returned qualitatively similar results. Following Jensen and Oster (2009) we also use cable TV ownership to proxy for connections with the outside world, and although some statistical

[1] Note that we do not address the other common concern with bonding social capital in that it can limit people to not wanting to deviate too far from the norm.

significance is lost, we again see generally similar results.

We then compare the effect of these two types of social capital on the amount of firewood collected on communal lands. We find that bonding social capital reduces firewood collection directly, and by affecting how members react to what others are doing. Bridging social capital slightly decreases consumption of the CPR at low levels of bonding social capital, but erodes the effect of bonding social capital at higher levels of community trust. We also find evidence that it makes villagers less sensitive to the quality of the CPR.

This paper has several contributions. First, unlike previous theoretical literature which has focused primarily on the effect of bonding social capital we model and contrast the effect of both bonding and bridging social capital. Second, we explicitly model how social capital can affect vulnerability, which in turn, will determine the effectiveness of social sanction and the community's ability to enforce a cooperative solution. Third, we show that under some circumstances, some types of social capital can, in fact, can nearly erode the community's ability to manage CPRs. Fourth, like Schechter (2007), we use measures from a field experiment to capture trust within a village, and then empirically test whether this trust affects CPR management.

2 Background

Yunnan is a largely mountainous, rural province in the southwest of China. Over 60 percent of the land is forested, and has traditionally been used for logging. It contains the headwaters of six major rivers including the Yangtze, and has been labeled a biodiversity 'hot spot' (Conservation International, 2007). Deforestation is threatening habitat of endangered species such as the red panda, and has been blamed for severe flooding and landslides in the late 1990s.

Developing successful community forest management in Yunnan has long been a problem. For example, after the Household Responsibility System reallocated land to households in 1985, anecdotal evidence showed "*…villagers ventured into the forest to log at night, fearful that their neighbors would cut remaining forests* (Su, 2002)"[2]. On the other hand, a number of villages, such as Wenming and Mabuchong have track records of

[2] This is quoted from Weyerhaeuser *et al*. (2006).

successful forest management. By exploring the nature of social capital in the villages, we hope to be able to identify some of the characteristics that can help explain why local resource management has been successful in some regions and failed in others.

Yunnan is one of the poorest provinces in China. In our data, median cash rural income, not counting the value of agricultural and forest products consumed for home use, is under 6,000 CNY per household, or slightly over 2,000 CNY per working individual. Younger men are often sent to work in the neighbouring towns and cities and send money back to support the family, and around 12 percent of the household income comes from remittances. As in many developing countries, households are larger than the nuclear family: on average, our households have 1 child under the age of 16, and slightly fewer than 3 adults, and are 46% female.

Even after tenure reform in 2006, all villages have some communal land, which is managed by the natural villages. The head of the natural villages coordinates the local land use decisions largely through village-level meetings. Income from communal lands is divided among members either proportionally by household or by the number of hectares of land each household holds. Most households have some privately-owned land after tenure reform in 2006. A large majority of the households in our sample (80%) have some land for forestry (averaging 1.3 ha). All but three households have a small plot of land for agricultural production (average 0.5 ha and all households in our sample produce some agricultural product). Our sample largely consists of subsistence farmers, with only one quarter of their agricultural produce being sold on the market.

3 The Model

3.1 Risk Sharing and Vulnerability to Social Sanction

In this section, we model the relationship between social capital and vulnerability to social sanction for bridging and bonding social capital. The setting for this paper is a village economy where the community manages common land for firewood collection. All members have access rights, implying that the community is not able to exclude members who violate the rule of consumption. Each household has a certain level of bonding social capital, which allows them to help each other when one family has a negative shock, such as an illness in the family, and to benefit from unexpected boons, such as an extra high yield of watermelons from their individual plot. Some families in the village also have ties to other villages or cities, whether through a family member sending remittances, or through friends or relatives that have since moved to a larger urban centre. Having these connections outside the village helps a family cope with not only an idiosyncratic shock but also a village-level shock, such as a bad crop year, by giving them access to outside employment income, or to informal credit from those not suffering the shock. These shocks can be thought of as not only financial, but also emotional, such as a death in the family.

Assume that there are $N > 2$ community members in a village sharing the common source of firewood. A typical villager derives utility from using a quantity of firewood c_i and consuming the numeraire good c_{0i}. In our model, villager *i*'s consumption of the numeraire is subject to an idiosyncratic shock, μ_i, such as illness or injury. For simplicity, we assume the shock is normally identically distributed with mean zero and variance σ_μ^2.

Bramoullé and Kranton (2005, 2007) show that risk-sharing networks exist in rural communities. Assume there are N villagers in the village and M_i individuals outside the village directly share risks with user *i* in the stable risk-sharing network. Assume villager *i* shares risks with each of the $N-1$ individuals in the same village at the ratio r_A, and shares the risk with the M_i individuals outside the village who are directly bridging with at the ratio r_{mB}. Moreover, villager *i* can also indirectly share risks with the $\sum_{n \neq i}^{N} M_n$ individuals through other villagers in the same village at the ratio $r_A r_{nB} \left(n \neq i\right)$. We assume the M_i individuals directly bridging with user *i* is subject to the normally identically distributed shock $\mu_{im} \left(m = 1, 2, \cdots, M_i\right)$ with mean zero and variance σ_μ^2. User *i*'s consumption of the numeraire with risk-sharing is then denoted by:

$$c_{0i} + \theta_i \mu_i + r_A \sum_{n \neq i}^{N} \mu_n + r_{iB} \sum_{m=1}^{M_i} \mu_{im} + \sum_{n \neq i}^{N} \left(r_A r_{nB} \sum_{m=1}^{M_n} \mu_{nm} \right),$$

where $\theta_i \equiv 1 - \left(N-1\right) r_A - M r_{iB} - \sum_{n \neq i}^{N} M_n r_A r_{nB} \in \left(0,1\right)$ is the residual of own risk.

Moreover, we have $\theta_i \geq r_A$ and $\theta_i \geq r_{iB}$, which means that the degree of risk sharing is between zero and full.

Following the idea that the magnitude of risk sharing is positively correlated with the level of social capital (Carter and Maluccio, 2003; De Weerdt and Dercon, 2006), we assume r_A is an increasing function of bonding social capital, $A_i\left(i=1,2,\cdots,N\right)$, i.e. $r_A = f\left(A_1, A_2, \cdots, A_N\right)$ and $\frac{\partial r_A}{\partial A_i} > 0\left(i=1,2,\cdots,N\right)$, and r_{iB} is an increasing function of villager *i*'s bridging social capital, B_i, i.e. $r_{iB} = f\left(B_i\right)$ and $\frac{dr_{iB}}{dB_i} > 0$.

Assume each villager's numeraire consumption has a CARA utility function with the form, $v(x) = -\exp(-\gamma x)$, where γ is Arrow-Pratt coefficient of relative risk aversion. Villager *i*'s expected utility with the risk-sharing network is:

$$EU_i^a = u\left(c_i\right) + v\left(c_{0i}\right) - \frac{1}{2}\gamma\sigma_{1i}^2,$$

where

$$\begin{aligned}\sigma_{1i}^2 = &\left(1-\left(N-1\right)r_A - M_i r_{iB} - \sum_{n\neq i}^{N} M_n r_A r_{nB}\right)^2 \sigma_\mu^2 \\ &+\left(\left(N-1\right)\left(r_A\right)^2 + M_i\left(r_{iB}\right)^2 + \left(r_A\right)^2 \sum_{n\neq i}^{M} M_n\left(r_{nB}\right)^2\right)\sigma_\mu^2\end{aligned}.$$

If villager *i* is excluded from the risk-sharing network within the village, he can only share risks with those $M-1$ individuals outside the village who are directly bridging with. Villager *i*'s consumption of the numeraire good with shocks is then denoted by:

$$c_{0i} + \left(1 - M_i r_{iB}\right)\mu_i + r_{iB}\sum_{m=1}^{M_i}\mu_{im}.$$

The expected utility of villager *i* will be:

$$EU_i^b = u\left(c_i\right) + v\left(c_{0i}\right) - \frac{1}{2}\gamma\sigma_{2i}^2,$$

where $\sigma_{2i}^2 = \left(\left(1-M_i r_{iB}\right)^2 + M_i\left(r_{iB}\right)^2\right)\sigma_\mu^2$.

It is easy to show that the variance of consumption with less mutual insurance is greater than with more mutual insurance, i.e. $\sigma_{2i}^2 > \sigma_{1i}^2$. Thus, expected utility is higher with insurance, i.e. $EU_i^a > EU_i^b$. In other words, villagers benefit from pooling their risks with more villagers. We will formally show this result in the proof for the following proposition 1.

We model social sanction as excluding a villager from the risk-sharing network in the village. Assume that the deviators in the village will face the probability of being excluded from the risk-sharing networks, η, thus we can define the villager's vulnerability to social sanction as:

$$m_i = \eta\left(EU_i^a - EU_i^b\right).$$

Substituting EU_i^a and EU_i^b into the definition of vulnerability above and rearranging yields:

$$\begin{aligned} m_i &= \gamma\eta\sigma_\mu^2\left(1 - M_i r_{iB}\right)\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB}\right) r_A \\ &\quad - \frac{1}{2}\gamma\eta\sigma_\mu^2\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n \left(r_{nB}\right)^2 + \left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB}\right)^2\right)\left(r_A\right)^2. \end{aligned} \tag{1}$$

We then have the following proposition on the relationship between the vulnerability and social capital.

Proposition 1. *Villager i's vulnerability to social sanction is increasing with bonding social capital and decreasing with bridging social capital. Mover, the marginal effect of bonding social capital is decreasing with bridging social capital, i.e.:*

$$\frac{\partial m_i}{\partial A_i} > 0, \quad \frac{\partial m_i}{\partial B_i} < 0, \text{ and } \frac{d^2 m_i}{dA_i dB_i} < 0. \tag{2}$$

Proof: *See Appendix A*.

3.2 Social Capital and Community Governance of CPRs

We now consider how social capital affects the cooperative level of resource consumption. We know that individuals have the incentive to extract more CPR than the socially-optimal level since each individual only internalizes their direct costs of consumption, ignoring the externalities their consumption imposes cost on their neighbors. However, existence of some enforcement mechanism might alleviate the problem. In this section, we consider peer monitoring and social sanction in the form of excluding individuals from risk-sharing networks as the enforcement mechanism, and analyze the implications for CPR consumption.

Resource consumption is modeled as a two-stage game: In the first stage, the community coordinates to set a cooperative level of consumption and establishes a mechanism to enforce this level based on peer monitoring and social sanction; In the second stage, members of the community consume the CPR. Whether individuals deviate from the consumption level set in the first stage depends on two conditions: first, whether the expected utility of consuming the cooperative level is greater than under deviation, second, whether the ex-post consumption is greater than a subsistence level. If an individual with few resources who lives right at the subsistence level realizes a large negative income shock, they might consume more CPR to survive regardless of the threat of social sanction.

Assume that individuals with access to the CPR live in a closely knit community with frequent interaction. Thus, individuals may be able to determine their neighbour's consumption level based on mutual monitoring. Further, assume that monitoring is not costless, and that player *i*'s probability of being detected if deviated from the agreed-on consumption of the CPR is an increasing function other players' total monitoring effort. This monitoring investment includes activities such as hiking in the communal forest, or record keeping. Individuals are able to impose penalties on those who deviate from the cooperative level of consumption in the form of social sanction.

The game can be solved by backward induction. In the second stage of the game, each player has two strategies: one is to cooperatively extract the CPR at the level determined by a joint utility maximization, and the other is to non-cooperatively extract the CPR based on individual utility maximization, or individual utility from the CPR. Each player must expend constant marginal cost *d* (e.g. costs of fishing, or timber harvesting and selling on the market) to extract each unit of the CPR. Following McCarthy *et al*. (2000), we specify the utility from using the CPR as:

$$u(c_i) = c_i\left(a - b\sum_{n=1}^{N} c_n\right) - dc_i\,, \qquad (3)$$

where *a, b* and *d* denote the resource capacity, sensitivity to consumption, and constant marginal cost of consumption respectively.

In the case of non-cooperation, the reaction function of player *i* as a function of all other players' consumption (c_{-i}):

$$c_i\left(c_{-i}\right)=\frac{a-d}{2b}-\frac{1}{2}\sum_{n\neq i}^{N}c_n\ . \tag{4}$$

The structure of other players' reaction function is the same. Combing them gives the non-cooperative equilibrium consumption for each player and for the group:

$$\tilde{c}=\frac{1}{N+1}\frac{a-d}{b},\ \tilde{C}=\frac{N}{N+1}\frac{a-d}{b}\ . \tag{5}$$

If there exists some costless enforcement mechanism that enables the players to internalize the externalities associated with their consumption, the optimal consumption level should be the amount that maximizes the sum of each household's utility:

$$\left(\overline{c}_1,\overline{c}_2,\cdots,\overline{c}_N\right)=\underset{\{c_1,c_2,\cdots,c_N\}}{\arg\max}\sum_{n=1}^{N}u\left(c_n\right).$$

Substituting the specific utility function form in (2) and solving the maximization problem gives the cooperative levels of consumption for each player and for the group:

$$\overline{c}=\frac{1}{2N}\frac{a-d}{b},\ \overline{C}=\frac{1}{2}\frac{a-d}{b}\ . \tag{6}$$

In the rest of this paper, this level of consumption will be taken as the baseline to see whether there is over-consumption of the CPR given various levels of social capital. Since monitoring is not costless, the above optimal consumption is not enforceable since the marginal benefit of achieving the cooperative solution will be less than the marginal cost of that last unit of monitoring effort, and individuals always have incentive to deviate to obtain higher payoff.

Next, we assume that the level of enforceable cooperative consumption level is $\hat{c}_i\ \left(i=1,2,\cdots,N\right)$ and solve for player *i*'s level of consumption given that he deviates. We solve for the expected penalty and the required level of monitoring effort needed to keep player *i* from deviating and to enforce the cooperative solution.

If all other players cooperate and player *i* is not monitored, player *i*'s consumption under deviation is:

$$c_i\left(\hat{c}_{-i}\right)=\frac{a-d}{2b}-\frac{1}{2}\sum_{n\neq i}^{N}\hat{c}_n\ . \tag{7}$$

Player *i*'s utility from deviation is:

$$u\left(c_i\left(\hat{c}_{-i}\right),\hat{c}_{-i}\right)=c_i\left(\hat{c}_{-i}\right)\left(a-b\left(c_i\left(\hat{c}_{-i}\right)+\sum_{n\neq i}^{N}\hat{c}_n\right)\right)-dc_i\left(\hat{c}_{-i}\right), \tag{8}$$

and his utility from cooperation is:

$$u_i\left(\hat{c}_i,\hat{c}_{-i}\right)=\hat{c}_i\left(a-b\sum_{n=1}^{N}\hat{c}_n\right)-d\hat{c}_i\,. \tag{9}$$

Assume that the probability of being caught if deviated, π_i, is an increasing function of other users' total monitoring effort, $\sum_{n\neq i}^{N}s_n$. To simplify the analysis, we choose a simple form of monitoring technique following McCarthy *et al*. (2001):

$$\pi_i\left(\sum_{n\neq i}^{N}s_n\right)=\frac{\alpha\sum_{n\neq i}^{N}s_n}{1+\alpha\sum_{n\neq i}^{N}s_n}.$$

Player *i* will not deviate from the cooperative level of consumption if and only if: 1) the expected penalty is not less than the extra utility from deviation, where his penalty is his vulnerability to social sanction times the probability he gets caught; 2) the ex-post consumption is not lower than the subsistence level[3]. Thus we have the two following conditions for cooperation:

$$\pi_i\left(\sum_{n\neq i}^{N}s_n\right)m_i\geq\left(1-\pi_i\left(\sum_{n\neq i}^{N}s_n\right)\right)\left(u\left(c_i\left(\hat{c}_{-i}\right),\hat{c}_{-i}\right)-u\left(\hat{c}_i,\hat{c}_{-i}\right)\right), \tag{10}$$

and

$$\beta\hat{c}_i+c_{0i}+\theta_i\hat{\mu}_i+r_A\sum_{n\neq i}^{N}\hat{\mu}_n+r_{iB}\sum_{m=1}^{M-1}\hat{\mu}_{im}+\sum_{n\neq i}^{N}\left(r_Ar_{nB}\sum_{m=1}^{M-1}\hat{\mu}_{nm}\right)\geq\underline{c}, \tag{11}$$

where β is a coefficient of transferring the firewood to numeraire goods, $\underline{c}$ is the subsistence level of consumption, and $\hat{\mu}_i$ and $\hat{\mu}_{im}$ denote the realized shocks.

First we consider the case where the subsistence constraint (11) is not binding and focus on the penalty constraint (10). The monitoring effort by players to force player *i* to cooperate must be greater than or equal to some minimum effort such that it just equals

[3] Some of the resource users are poor and their consumption is not far above subsistence consumption. If a negative shock drives their consumption below subsistence level, they will consume as much resources as they can to survive, without following the rule of cooperative consumption.

the increase in utility from deviation divided by *i*'s vulnerability to social sanction:

$$\sum_{n\neq i}^{N} s_n \geq \sum_{n\neq i}^{N} \hat{s}_n = \frac{u\left(c_i\left(\hat{c}_{-i}\right),\hat{c}_{-i}\right)-u\left(\hat{c}_i,\hat{c}_{-i}\right)}{\alpha m_i}. \tag{12}$$

Resource player *i*'s perceives his choices as being: (a) extracting the cooperative level, $\hat{c}_i$ and monitoring other players at the cost $\hat{s}_i$, or (b) extracting the non-cooperative level of $c_i\left(c_{-i}\right)=\frac{a-d}{2b}-\frac{1}{2}\sum_{n\neq i}^{N}c_n$ without monitoring other players. For the cooperative equilibrium to exist, all players must have larger payoffs under option (a) than (b).

Next, we explicitly find the conditions that allow a cooperative equilibrium to exist. Returning to the first stage of the game, the community maximizes the total welfare by choosing the cooperative consumption levels. The community's problem is to maximize joint utility less the required enforcement costs[4]:

$$\max_{\{c_1,c_2,\cdots,c_N\}} \sum_{i=1}^{N}\left(u\left(c_i\right)-\sum_{n\neq i}^{N}s_n\right)$$

s.t.

$$c_i=\begin{cases}\hat{c}_i & if\ \ s_i\geq \hat{s}_i\\ c_i\left(c_{-i}\right) & otherwise\end{cases} \quad for\ any\ i=1,2,\cdots,N.$$

Substituting the minimum level of monitoring effort needed to sustain the cooperative equilibrium, $\hat{s}_k$, into the problem above, the group's cooperative level of consumption is thus given by:

$$\hat{c}_i=\arg\max_{\{\hat{c}_1,\hat{c}_2,\cdots,\hat{c}_N\}}\sum_{i=1}^{N}\left(\left(1+\frac{1}{\alpha m_i}\right)u\left(\hat{c}_i,\hat{c}_{-i}\right)-\frac{1}{\alpha m_i}u\left(c_i\left(\hat{c}_{-i}\right),\hat{c}_{-i}\right)\right). \tag{13}$$

For the cooperative equilibrium to be enforceable, we also need to have the condition that the utility for each player from cooperative consumption and monitoring must be greater than the utility from no monitoring together with deviation[5], i.e.:

---

[4] The utility from consuming the numeraire goods is not included in the objective function since it is not related with the consumption of the CPR.

[5] Assume in the non-cooperative equilibrium, no social sanction is imposed and the mutual insurance still exists.

$$\hat{U}_i \equiv u\left(\hat{c}_i, \hat{c}_{-i}\right) - \sum_{n \neq i}^{N} \hat{s}_n \geq \tilde{U}_i \equiv u\left(\tilde{c}_i, \tilde{c}_{-i}\right) \quad \textit{for } \forall i = 1, 2, \cdots, N. \tag{14}$$

Substituting $\hat{s}_k$ into the condition (14), we then have:

$$\left(1 + \frac{1}{\alpha m_i}\right) u\left(\hat{c}_i, \hat{c}_{-i}\right) - \frac{1}{\alpha m_i} u\left(c_i\left(\hat{c}_{-i}\right), \hat{c}_{-i}\right) \geq u\left(\tilde{c}_i, \tilde{c}_{-i}\right) \quad \textit{for } \forall i = 1, 2, \cdots, N. \tag{15}$$

Therefore the enforceable consumption for user *i* is given by (13) if the condition in (15) is satisfied, otherwise the enforceable consumption is equal to the non-cooperative equilibrium consumption given in (5).

Proposition 2: *If the subsistence constraint is not binding, the enforceable consumption of the CPR for player i is*:

$$\begin{aligned} \hat{c}_i &= \frac{2\left(\sum_{n=1}^{N} m_n - (N-1) m_i\right) + (N+1)}{4\sum_{n=1}^{N} m_n + (N+1)^2} \frac{a-d}{b} && \textit{if } \max_{\{j=1,2,\cdots,N\}} \left(m_j\right) \leq f\left(\bar{m}\right), \\ \hat{c}_i &= \tilde{c}_i = \frac{1}{N+1} \frac{a-d}{b} && \textit{otherwise}, \end{aligned} \tag{16}$$

in which $f\left(\bar{m}\right) = \left(1 + \frac{N-1}{(N+1)^2}\right)\bar{m} + \frac{(N-1)(3N+5)N\bar{m}}{(N+1)^2\left(4N\alpha\bar{m} + (N+3)\right)}$, *and* $\bar{m}$ *denotes the average vulnerability of the users' group. Moreover, if* $\max_{\{j=1,2,\cdots,N\}} \left(m_j\right) \leq f\left(\bar{m}\right)$, *user i's enforceable consumption is decreasing with his/her vulnerability by a decreasing rate, i.e.:*

$$\frac{d\hat{c}_i}{dm_i} < 0 \quad \text{and} \quad \frac{d^2\hat{c}_i}{d\left(m_i\right)^2} > 0. \tag{17}$$

Proof: *See Appendix B*.

Proposition 2 implies that cooperative consumption under costly monitoring exists if and only if each user's vulnerability to social sanction is not much bigger than the average vulnerability. The intuition is that, for each user *i*, the bigger vulnerability to social sanction, the lower cooperative consumption of the CPR and then the lower utility.

If user *i*'s vulnerability is bigger than a specific critical value, he/she will deviate from the cooperative consumption and all the users will be end up with the non-cooperative consumption.

Summation of (13) over *i* gives the group's total consumption under costly monitoring,

$$\begin{aligned} \hat{C} &= \sum_{n=1}^{N} \hat{c}_n = \frac{2\sum_{n=1}^{N} m_n + N(N+1)}{4\sum_{n=1}^{N} m_n + (N+1)^2} \frac{a-d}{b} \qquad && if \max_{\{j=1,2,\cdots,N\}} (m_j) \leq f(\bar{m}), \\ \hat{C} &= \sum_{n=1}^{N} \tilde{c}_n = \frac{N}{N+1} \frac{a-d}{b} && otherwise, \end{aligned} \tag{18}$$

Expression (18) implies that the cooperative consumption of CPRs induced by mutual monitoring and social sanction lies between cooperative consumption under costless monitoring and the non-cooperative consumption, i.e. $\bar{C} \leq \hat{C} \leq \tilde{C}$. In short, community governance may mitigate the overconsumption of CPRs, but cannot completely eliminate it.

When the condition $\max_{\{j=1,2,\cdots,N\}} (m_j) \leq f(\bar{m})$ is satisfied, the enforceable cooperative level of consumption will be changing with the stock of bonding and bridging social capital. The relationship between player *i's* consumption and the two types of social capital is given by the following proposition.

Proposition 3. *If the subsistence constraint is not binding, player i's consumption of CPR under cooperative strategy is decreasing with bonding social capital and increasing with bridging social capital. Moreover, the marginal effect of bonding social capital is decreasing with bridging social capital, i.e.*

$$\frac{\partial \hat{c}_i}{\partial A_i} < 0, \quad \frac{\partial \hat{c}_i}{\partial B_i} > 0, \text{ and } \frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} > 0. \tag{19}$$

Proof: *See Appendix C.*

Proposition 3 implies that higher bonding social capital induces a more restrictive cooperative level of consumption given a fixed level of bridging social capital, while higher bridging social capital reduces enforceability consumption outcomes, implying the feasible cooperative level of CPR consumption is larger. The result also implies that the combination of high bonding and high bridging social capital might result in the same level of CPR consumption as a combination of low bonding and low bridging social capital. That said, a combination of high bonding and low bridging social capital induces lower consumption of CPRs than that of low bonding and high bridging social capital. These results may help explain the conflicting findings often seen in empirical research: that high bonding social capital cannot induce lower consumption of CPRs for certain. The point is that they neglect the offsetting effect of bridging social capital on the effectiveness of bonding social capital. Two communities endowed with similar resource characteristics and bonding social capital but different enough bridging social capital will for certain have different levels of consumption of CPRs in equilibrium.

Now we need to look at the subsistence constraint in (11). The sum of players' shocks will still be approximately equal to zero. For simplicity, consider the case that only player i is subject to a large negative shock, $\hat{\mu}_i < 0$, $\sum_{n \neq i}^{N} \hat{\mu}_n = 0$ and $\sum_{m=1}^{M_i} \hat{\mu}_{nm} = 0 \ for \ \forall n = 1, 2, \cdots, N$. Assume the negative shock $\hat{\mu}_i$ is big enough such that player i's ex-post consumption under the cooperative strategy is below the subsistence level, i.e. $\beta \hat{c}_i + c_{0i} + \theta_i \hat{\mu}_i < \underline{c}$. User i will over-consume the CPR at the level $\widehat{c}_i > \hat{c}_i$ so that his/her total consumption equal to the subsistence level, then we have:

$$\widehat{c}_i = \frac{1}{\beta}\left(\underline{c} - c_{0i} - \theta_i \hat{\mu}_i\right). \tag{20}$$

Then we have the following proposition on the relationship between the consumption and social capital.

Proposition 4: *If the subsistence constraint is binding, player i's consumption of CPR is decreasing with both bonding social capital and bridging social capital. Moreover, the marginal effect of bonding social capital is not changing with bridging social capital, i.e.:*

$$\frac{\partial \hat{c}_i}{\partial A_i} < 0, \quad \frac{\partial \hat{c}_i}{\partial B_i} < 0, \text{ and } \frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} = 0. \tag{21}$$

Proof: *See Appendix D.*

If there is a large negative shock realized, a villager with high level of bridging social capital is more capable of getting financial aid from outside the community, therefore the incentive to over-consume the CPR to maintain the subsistence level is not as high for a villager with low bridging social capital. Therefore, for individuals close to the subsistence level, bridging social capital can be good for maintaining cooperation in the community governance of CPR.

From our propositions, we get the following testable hypotheses:

(H1) Bonding social capital increases vulnerability to social sanction, and therefore decreases consumption.

(H2) bridging social capital decreases vulnerability and thus may erode the effect of bonding social capital, increasing consumption.

(H3) However, given a subsistence level of consumption, by providing access to risk sharing, bridging social capital can help conserve CPR.

4 Data

We survey 600 families in 30 villages in Yunnan Province, covering a total of 2,818 people. We select 5 counties in northwestern and southwestern Yunnan Province[6], randomly select 6 administrative villages in each, and then randomly select 20 households from each administrative village. In our survey, we ask extensive questions about income, household characteristics and purchasing behaviour. In particular, we are interested in the consumption of fuel. We also ask about the amount of time household members spend outside the village and village-level characteristics, such as the distance to the nearest road. We use these measures of connection with the outside world as indicators of bridging social capital.

[6] The counties covered are Yongping, Jianchuan, E'shan, Pingbian, and Jinggu.

4.1 Trust Game: Bonding Social Capital

To determine the level of bonding social capital, we conduct a field experiment to measure villager's trust of each other closely following Schechter (2007)[7]. We randomly select household heads from each village and pair them with another anonymous village member. To ensure each partner's identity remains hidden, we conduct the interviews in the home as opposed to meeting in a central hall.

In the game, each player is randomly chosen to be a sender or a recipient. We give all players 20 CNY at the beginning of the game, about the equivalent of one day's wages. Then the sender is given a choice of sending 0, 5, 10, 15 or 20 CNY to the anonymous recipient, who they know lives in the same village. They are told that the recipient will receive double the amount sent, and will then have a choice of how much to send back. Because fairness is a powerful motivating force in Chinese culture, the sender is also informed that the recipient also received 20 CNY, to eliminate equity concerns as a motivation for sending money. The sender then puts the amount they wish to send into an envelope for the enumerator. The sender is then asked how much money she expects to receive back.

When the recipient receives the envelope containing now double the amount sent, he is asked how much he expects to receive. Then, after opening the envelope, he is asked how much he wishes to return. That amount is then given to the sender.

Although we observe the amount sent by each, to have a comparable measure across senders and recipients, we use the amount the sender and recipient expect to receive as a measure of bonding social capital. This amount reflects the degree to which people trust their fellow villagers to behave in a trustworthy manner. As one might expect, this figure is highly correlated with the amount sent by the sender (87%) while it is less correlated with the amount sent by the recipient.

As found in other trust games, the majority of our sample sent money and expected to receive money. The average amount sent was about 9 CNY, and is only one CNY less than the average amount returned. Of people that sent some positive amount, they sent approximately 11 CNY, which is more than half of their starting amount. On average, the

[7] For details on the game and results, see Gong *et al*. (2010).

recipients returned 60 percent of the funds sent. The summary of the findings of the game are given below in Table 1[8].

Table 1: Results of Trust Game

Player 1	Obs	Mean	Std. Dev.	Min	Max
Money expected	297	8.906	7.675	0	40
Money sent	300	8.383	6.385	0	20
Money received	300	10.073	8.673	0	35
% who sent money	230	76.7			
% of money sent, returned	230	119.8	41.1	0	300
Player 2					
Money expected to be sent (1/2 amount expected to be received)	300	8.85	5.40	0	20
Money received	300	16.77	12.77	0	40
Money Returned	300	10.01	8.66	0	35
% who sent money (of those who received money)	223	97.0			
% of returned of money received	230	59.5	19.6	0	150

Although we trained players in the nature of the game using tokens before asking them to send money, we were still concerned that those players with higher education understood the game better, and may have sent more. Since we do not have any explicit reason to believe trust is improved with education, we are concerned that is we directly use the amount players expect to receive, it might contaminate our results if both that amount and firewood management are affected by education. So to generate our measure of bonding, we first regress the amount expected against education of the household head and whether the person is the sender or the receiver, and then use the residuals plus the constant as our measure of bonding social capital. As an aside, results did not qualitatively change when we used the expected amount directly. Results for this initial regression are given in Table 2. Interestingly, the player number did not appear to matter, while education was highly significant in determining the amount sent.

8 The authors hope to develop a close friendship with the recipient who returned 150% of the money s/he received.

Table 2: Amount Expected Regressed on Education and Player Number

Amount Expected	Coef.	Std. Err.	P>|t|
Education of hh head	0.316	0.080	0.000
Recipient (1 = player 2)	-0.210	0.538	0.696
Constant	7.201	0.577	0.000
Number of obs = 597			
R-squared = 0.025			

Authors have debated whether social capital should be considered primarily at the village or at the individual level. We find as much within-village variation in our bonding social capital measure as we observe among villages as well as observing substantial variation in firewood collected within a village. Thus, we use bonding at the individual level to explain the individual decision of how much firewood to collect on public lands.

4.2 Bridging Social Capital

To capture bridging social capital, we use the percentage of days members of the household worked outside of the township. The idea is that the more time a household member spends outside the region, greater the connection with the outside world, and therefore the greater the potential insurance against village-specific shocks. One might be concerned that this variable could affect firewood demand simply by reducing the cooking requirements of the household. To control for this concern, we include the number of household members living at home in the regression for firewood.

As alternative measures for bridging social capital, we also use the number of household members working outside the township, the percent of members working outside the township, and the percent of days worked outside the county, and all returned qualitatively similar results. Following Jensen and Oster (2009) we also use cable TV ownership to proxy for connections with the outside world, and although some statistical significance is lost, we again see generally similar results.

4.3 Measure of the CPR

We are interested in observing how the two types of social capital affect firewood management. While we would ideally like to know how much land is publically held per village, we only observe the amount of total land per administrative village. Thus, to measure firewood collection, we use the logged amount of firewood collected on public lands divided by the amount of forestland in the administrative village to get a measure of firewood collected per forest. We are missing information on forestland on one administrative village, dropping our sample size to 580. Summary statistics are presented in Table 3.

Table 3: Summary Statistics

Variable	Obs	Mean	Std. Dev.
ln(firewood collected per mu)	580	-6.399	3.653
Bonding SC	597	7.201	6.541
Bridging SC	600	28.241	29.805
Natural village forest yield (kg/mu)	600	4.120	2.816
HH resource capacity (kg)	599	58.374	169.419
Dummy if family owns pigs	600	0.448	0.498
Number of hh members at home	600	4.035	1.548
Slope (high number = low slope)	599	1.155	0.786
Household expenditure less energy (1,000 CNY)	600	8.415	6.921
ln(productive assets) (CNY)	600	6.698	2.786

5 Empirical Model and Results

We are interested in observing how the amount of firewood collected on communal land is affected by the amount of bonding and bridging social capital, the consumption of other villagers, the average village resource capacity, the productive assets and total income of the household and the weighted slope of household forest plots.[9] Thus, we are interested in estimating the following relationship:

$$c_{iv} = \mu + \alpha A_{iv} + \beta B_{iv} + \lambda A_{iv} B_{iv} + r_1 \alpha_v + r_2 d + \delta_1 x + \varepsilon_i,$$

where i and v stand for household and village, c is the (log) quantity of firewood consumed per area of land, μ is an intercept term, which for several models includes village fixed effects, A is bonding social capital, and B is bridging social capital. The variable a is the quality of the resource, d is the cost of consuming firewood on the household's private land, which includes the slope of the land and the quality and quantity of the household forest resource, and x is a vector of household characteristics, such as number of members living at home, whether the family owns pigs and household

[9] We also tried including the amount of grain harvested under the assumption that grain stalks might be used as fuel. However, we were informed that this practice is not common in Yunnan, which corresponded with the insignificance of the estimated coefficient.

expenditure. As in our model, we also control for carrying capacity or forest yield of those lands. While we do not explicitly observe the cost of villagers collecting firewood on public lands, we do have measures of the cost to the household of consuming their private resources. Thus, we also want to control for the cost to a household of collecting firewood on their private lands, so we include the household forest resources defined as forest plot area × yield, and the area-weighted average slope of the household forest plots. We also included distance to the household forest plots, but this measure was highly correlated with slope so we did not include it in our final model specification.

Anecdotally, we heard that firewood demand is affected by whether the family owns pigs or not, since food is often cooked for the livestock. Thus, we include a dummy for pig ownership. Last, since the amount of fuel to use is determined alongside household expenditure, we include total household expenditure, less expenditure on energy. We also instrument for total expenditure using household assets and education, and find little change in our results. We cluster errors by natural village. Results are presented in Table 4. As alternative measures for bridging social capital, we use the percent of household members working outside the township and cable TV ownership, and all returned qualitatively similar results as reported in Table 4A[10].

In the first model in Table 4, we run the regression with no fixed effects. In the second model, we include dummy variables for the administrative villages. As our model suggests bridging social capital may erode the vulnerability to social sanction provided by bonding social capital, in models 3 through 5, we include an interaction term between the two types of social capital. In the last model in Table 4, we instrument for total expenditure using the natural logarithm of total household assets, education of the household head and total household size. Tests indicate that the instruments identify total expenditure, and that overidentification is not a concern (Hanson's J statistic gives a p-stat of 0.578 indicating we cannot reject the hypothesis of no overidentification).

In the first two models in Table 4, without the interaction term, we see some weak evidence that bonding decreases consumption of firewood, although the coefficient is only significant at the 6 percent level in the model with administrative village fixed

[10] We also use the number of members working outside the township and the percent of days worked outside the county as alternative indicators of bridging social capita, and all returned qualitatively similar results. Those results are not reported to save space.

effects. Bridging social capital on its own does not appear to have a significant effect on firewood collection. However, when we include the interaction term, both bridging and bonding social capital coefficients become highly significant. One might be concerned that these results are a product of multicollinearity, but our tests indicate that this is not the case (all variance inflation factors are less than 3.5). We observe that, on their own, both types of social capital reduce the consumption of firewood. For those 25 percent of households with no measured bridging social capital, a one CNY increase in bonding social capital generates an 8 percent decrease in the collection of firewood. For those approximately 18 percent of households who, in the trust game, did not expect any money to be sent or returned, a one percent increase in the number of days household members are away decreased the amount of firewood collected by 0.9 to 1.3 percent.

Observing the effect of each type of social capital in the presence of the other is more complicated since interaction term between Bridging and Bonding is positive and significantly different from zero. When calculated at the median amount of bridging and bonding social capital, only the effect of bonding social capital remains significant, reducing firewood consumption by around 5 percent (see Table 5). At high levels of bridging social capital, bonding appears to have no effect, while bridging social capital only reduces firewood consumption at the lowest levels of bonding.

The signs on the control variables are mostly as expected. Villagers are sensitive to what others do: the more firewood other village members collected, the more each household collects itself. One should be cautious assigning causality here since this decision is clearly simultaneous, but since even the smallest village had more than 100 households, we hope that the actions of any one household have little effect on the total consumption of the village.

The lower the household's resource capacity, and the higher the slope, the more firewood collected on public lands. Similarly, if the household owns pigs, the family collects more firewood, at least when we control for administrative village fixed effects. The yield of the village forest and the total number of household members living at home appear to have little effect on firewood collection.

Table 4: Firewood Collected Per Area Regressed on Social Capital

Independent variables	(1)	(2)	(3)	(4)	(5) (IV for Expenditure)
Bonding SC	-0.033	-0.043**	-0.077**	-0.084***	-0.081***
(money expected)	(0.021)	(0.017)	(0.032)	(0.028)	(0.028)
Bridging SC	-0.002	-0.006	-0.013*	-0.016**	-0.013
(% days working away)	(0.006)	(0.006)	(0.007)	(0.006)	(0.009)
Bond*Bridging			0.001*	0.001**	0.001**
			(0.001)	(0.001)	(0.001)
Natural village forest	-0.152	-0.139	-0.146	-0.138	-0.149
yield	(0.110)	(0.146)	(0.110)	(0.147)	(0.140)
HH resource capacity	-0.004***	-0.002***	-0.004***	-0.002***	-0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
dummy if family owns	-0.006	0.006	-0.006	0.006	0.006
pigs	(0.005)	(0.004)	(0.005)	(0.004)	(0.004)
number of hh members	0.095	-0.002	0.106	0.006	0.033
at home	(0.110)	(0.087)	(0.111)	(0.088)	(0.095)
Slope (high number =	-0.792***	-0.174	-0.815***	-0.196	-0.196
low slope)	(0.252)	(0.182)	(0.252)	(0.184)	(0.095)
Total Expenditure less	-0.021	-0.046*	-0.017	-0.043*	-0.076
energy (10000s)	(0.030)	(0.024)	(0.029)	(0.023)	(0.069)
Administrative village fixed effects	No	Yes	No	Yes	Yes
R-squared	0.092	0.317	0.096	0.321	0.359
Number of obs.	576	576	576	576	576
Number of clusters	58	58	58	58	58

Table 4A: Results Using Other Measures of Bridging Social Capital

	(1A)	(2A)	(3A)	(4A)	(5A) Cable TV
Bonding SC	-0.033	-0.043**	-0.055*	-0.071***	-0.060***
	(0.021)	(0.017)	(0.028)	(0.023)	(0.021)
Bridging SC (% of household members working outside of township except Model 5A, where it is cable TV)	-0.002 (0.009)	0.002 (0.008)	-0.014 (0.013)	-0.014 (0.010)	-0.801 (0.579)
Bonding * Bridging			0.002	0.002**	0.050
			(0.001)	(0.001)	(0.032)
Natural village forest yield	-0.151	-0.144	-0.146	-0.138	-0.134
	(0.110)	(0.148)	(0.111)	(0.151)	(0.156)
HH resource capacity	-0.004***	-0.002***	-0.004***	-0.002***	-0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
dummy if family owns pigs	-0.006	0.006	-0.005	0.006	0.006
	(0.005)	(0.004)	(0.005)	(0.004)	(0.004)
number of hh members at home	0.095	0.029	0.097	0.028	0.030
	(0.108)	(0.094)	(0.108)	(0.094)	(0.085)
Slope (high number = low slope)	-0.789***	-0.178	-0.801***	-0.201	-0.172
	(0.251)	(0.183)	(0.252)	(0.186)	(0.182)
Total Expenditure less energy (10000s)	-0.023 (0.031)	-0.054** (0.025)	-0.023 (0.032)	-0.054** (0.025)	-0.048** (0.023)
Administrative village fixed effects	No	Yes	No	Yes	Yes
R-squared	0.092	0.315	0.093	0.319	0.316
Number of obs.	576	576	576	576	576
Number of clusters	58	58	58	58	58

Table 5: Marginal Effect of Social Capital at Different Percentiles of Bonding and Bridging Calculated from Regression Results Presented in Table 3

Model 3 (no fixed effects)	25%	Median	75%
Marginal effect of Bonding at percentiles of Bridging SC	-0.077**	-0.046**	-0.006
	(0.032)	(0.022)	(0.024)
Marginal effect of Bridging at percentiles of Bonding SC	-0.009	-0.002	0.001
	(0.006)	(0.006)	(0.006)
Model 4 (village fixed effects)			
Marginal effect of Bonding at percentiles of Bridging SC	-0.084***	-0.055***	-0.017
	(0.028)	(0.019)	(0.018)
Marginal effect of Bridging at percentiles of Bonding SC	-0.013**	-0.006	-0.003
	(0.006)	(0.006)	(0.006)

Next, we interact the bridging and bonding measures with the resource quality and productive assets. Results are presented in Table 6.

Table 6: Interacting Social Capital with Forest Resource Quality and Productive Assets

	(6)	(7)
Bonding SC	-0.170**	-0.162***
	(0.076)	(0.057)
Bridging SC	-0.033***	-0.018
	(0.012)	(0.012)
Bonding * Bridging SC	0.001*	0.001*
	(0.001)	(0.001)
Bonding* forest yield	0.005	0.002
	(0.008)	(0.006)
Bonding* productive assets	0.011	0.010
	(0.009)	(0.008)
Bridging* forest yield	-0.004**	-0.005***
	(0.002)	(0.002)
Bridging* productive assets	0.006***	0.004***
	(0.001)	(0.001)
Natural village forest yield	-0.071	0.003
	(0.122)	(0.132)
HH resource capacity	-0.004***	-0.002***
	(0.001)	(0.001)
dummy if family owns pigs	-0.004	0.005
	(0.004)	(0.004)
number of hh members at home	0.122	0.012
	(0.108)	(0.087)
Slope (high number = low slope)	-0.881***	-0.264
	(0.268)	(0.198)
Total Expenditure less energy (10,000s)	-0.024	-0.047**
	(0.024)	(0.018)
ln(productive assets)	-0.355***	-0.194**
	(0.098)	(0.092)
Administrative village fixed effects	No	Yes
R-squared	0.123	0.333
Number of obs.	576	576
Number of clusters	58	58

First, we see that bridging reduces firewood collection if people are asset-poor, but also reduces people's sensitivity to resource capacity. Since people do not seem to be sensitive to resource quality to begin with, this result may be picking up the tragedy of the commons. In other words, at high levels of bridging social capital, villagers actually collect more firewood if forests are already depleted in a rush to consume the resource before it is gone.

Neither bonding interactions are significantly different from zero. Overall, bonding social capital is significant on its own at zero levels of bridging social capital and average forest quality and asset levels. When the marginal effects are calculated, bridging social capital no longer has a significant effect on its own. It appears to act primarily through the interaction terms with bonding, resource capacity and assets.

Endogeneity of social capital

One might well be concerned that bridging and bonding social capital, along with forest management, are outcomes of underlying individual and community characteristics, and are therefore all co-determined. To address this concern about endogeneity, we instrument for bridging and bonding social capital.

Because much of the factors that affect bridging and bonding social capital are measured at the administrative village level, we use township fixed effects for our first stage regressions. For bonding social capital, we use the number of women in the household, the number of sick people in the household, and the percent of family members over the age of 65 in 2000. We include whether the family is in the majority ethnic group, whether they have the same last name as the dominant family in the village. We also include the length of time the household has been in the village, the number of households in the village and whether the village had a fish pond. No single variable was a particularly strong instrument for bonding social capital, so we included several. None of these variables individually or collectively affected firewood collection (collectively they had a p-stat of 0.555).

The argument for including the number of women and the percent of senior citizens is that both of these groups may be more likely to interact with their fellow villagers than the working men. We consider the number of senior citizens from six years earlier on the assumption that newly retired family members may take some time before developing a community of village colleagues. Second, if a household has a sick member, they may be forced to rely more on their fellow villagers for help and moral support, building trust. Third, we assume that the longer a household has lived in a village, the stronger ties they may have to their neighbours. Fourth, both relationship variables might capture the relative status of the household in the village. Fifth, we show in the model that larger villages may be able to provide better insurance against idiosyncratic shocks, increasing an individual's cost of social sanction. That said, we might anticipate that after reaching some critical number of households, people in larger villages might not be able to interact as much as those in smaller communities, decreasing the level of bonding social capital. Last, a village with a fish pond will have more incentive to develop rules regulating its use, which in turn might build management capacity and trust.

The percent of days members of a household spend working outside the township are likely a function of accessibility, education and whether the household has surplus labour. Thus, our instruments for bridging social capital include the number of household members who are registered as non-agricultural, making migration easier. Second, we include the level of education of the household head, assuming that more highly educated households may have better information and access to off-farm employment. Last, we include the overall household size and the number of children in the house under the age of 6, assuming that the former may indicate excess labour, whereas the latter places demand on that labour at home. Because the percent of days spent outside the township is censored at zero, we estimate the first stage using a tobit and use both the predicted levels and predicted probability of observing a non-zero outcome as instruments (see Baylis and Perloff 2010 for a proof). Results from the first stages are given in Table 7.

Last, to instrument for the interaction term, we interact the bridging and bonding variables predicted by our first stage regressions. R-squared for the first stages are relatively low, ranging from 0.09 for bonding to 0.16 for Bridging. However, all three regressions allow us to reject the weak instrument hypothesis, while also allowing us to reject overidentification.

Given that the error terms for the various first stage regressions are likely correlated, we use three-stage least squares for our regression. Table 8 presents our results for firewood consumption with instrumented social capital. As can be seen, these results are qualitatively very similar to those above in Table 3. An interesting result is that the instrumented social capital terms have larger coefficients than those without. This finding might indicate that the endogeneity acts to suppress the coefficient - that is, that reduced firewood collection induces lower bonding and bridging social capital - as opposed to inducing increased social capital.

Table 7: First Stage of IV Regression

Bonding		Bridging (% days worked outside township)	
# of women in household	0.401* (0.211)	# of non-agricultural hukou members in household	6.238*** (1.870)
# of self-reported sick household members	1.971 (1.432)	Years of schooling for household head	0.766 (0.669)
% of senior citizens in 2000	2.349 (1.985)	# of household members	5.769*** (1.134)
Member of the largest ethnic group	0.252 (1.030)	# of preschool children in household	-7.809*** (2.682)
Member of the largest village surname	-0.708 (0.546)	Age of household head	-0.061 (0.153)
# of years living in village	-0.022 (0.015)		
# of households in village	0.024*** (0.006)		
# of households in village^2 (/100000)	-0.162*** (0.051)		
Fishpond (mu)	0.124** (0.068)		
Std. dev. of village housing assets	-2.684*** (0.816)		
Includes township fixed effects	Yes		Yes
R-squared	0.09		NA
R-squared of excluded instruments	0.07		0.11
Test of excluded instruments (F-stat)	11.68		16.10
Number of obs	588		600

Table 8: Three-Staged Least Squares Result on Firewood Collection as a Function of (Instrumented) Social Capital

	(1)	(2)	(3)	(4)
Bonding SC	0.025	-0.440***	-0.323*	-0.678***
	(0.073)	(0.149)	(0.168)	(0.174)
Bridging SC	0.003	-0.007	-0.094**	-0.123***
	(0.017)	(0.015)	(0.044)	(0.039)
Bond*Bridging			0.012**	0.016***
			(0.006)	(0.006)
Natural village forest yield	-0.138**	-0.069	-0.086	-0.124
	(0.057)	(0.106)	(0.073)	(0.112)
HH resource capacity	-0.005***	-0.002*	-0.005***	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Dummy if family owns pigs	-0.002	0.003	-0.001	0.006
	(0.003)	(0.004)	(0.004)	(0.004)
Number of hh members at home	-0.063	0.103	-0.022	0.168
	(0.139)	(0.143)	(0.167)	(0.152)
Slope (high number = low slope)	-0.659***	-0.296	-0.857***	-0.471**
	(0.198)	(0.209)	(0.240)	(0.225)
Total Expenditure less energy (10,000s)	0.195**	-0.037	0.235***	-0.008
	(0.082)	(0.069)	(0.081)	(0.071)
Village fixed effects	No	Yes	No	Yes
Number of obs	567	567	567	567

6 Discussion and Conclusions

We find that bonding and bridging social capital appear to act as substitutes for one another, where both types of social capital reduce consumption of firewood in the absence of the other, but where high levels of both do not generate strong levels of common pool resource management. We first develop a model of social capital as facilitating risk-pooling, and demonstrate how bridging might erode the effect of vulnerability to social sanction induced by bonding social capital.

We next test this relationship between bonding and bridging empirically, by comparing the collection of firewood on public lands to our measures of individual bridging and bonding social capital. As in our theoretical model, we find that the two types of social capital both reduce consumption, but that they also act as substitutes for each other. Although we cannot say definitively which type of social capital erodes the other, we do see evidence that bridging appears to erode bonding, whereas the reverse is not as likely. For example, when using alternative measures of bridging social capital, such as the percent of household members who work outside the township, bridging social capital rarely has a significant effect on its own, and only acts through the interaction term on bonding social capital. Similarly, when we calculate the marginal effects of bridging and bonding, bridging only significantly reduces firewood consumption at the lowest levels of bonding, while bonding social capital significantly reduces consumption of firewood at median levels of bridging social capital.

Our findings are consistent with the results of Dayton-Johnson (2000), who shows strong evidence that bonding social capital is good for cooperation and some evidence that bridging social capital is bad for cooperation. He finds that a higher wage, and therefore higher opportunity cost decreases a communities ability to cooperate in maintaining an irrigation system. We posit that there may be another explanation in this context, where high wage implies higher ability to make money from outside the village, then less vulnerability to social sanction, and thus less willing to cooperate. Cases collected in Berkes and Folke (1998) shows that strong kinship-based relationships is essential for promoting and enforcing collective action, moreover relatively isolated systems perform better.

When we further interact bridging and bonding social capital with sensitivity to resource use and asset ownership, we observe that while none of the bonding interaction terms were significantly different from zero, bridging social capital appears to reduce sensitivity to resource capacity and reduce consumption for those asset-poor households. Once these interaction terms are included, the direct effect of bridging social capital essentially disappears. Since we do not find that households are particularly sensitive to resource capacity, it is particularly concerning that connections with outsiders further induces consumption of low-yielding resources. We believe this may be reflecting a tragedy of the commons argument, where households hurry to consume a weakened resource fearing that if they do not, their neighbours will rush to consume it first.

Last, because we might be concerned that both types of social capital are jointly determined alongside community resource management, we instrument for bridging and bonding using various household and village characteristics. While we cannot be completely certain that none of these characteristics are associated with firewood collection, we cannot reject the hypothesis of no overidentification, while we do find that they help explain the levels of social capital. In particular, village size, the existence and size of the fishpond, the variance of housing assets in the village and the number of women in the household all go to explain the household level of social capital. As our model predicts, bonding social capital initially increases with the size of the village until it reaches around 740 households, when increasing the village size further dilutes trust. The existence and size of a fishpond implies that villagers have another resource to manage, which may help build cooperation. Fishponds are also associated with a higher probability of having irrigation in the village, which also poses another common pool resource problem for the community to solve. While we might believe that the percent of women in a household may affect firewood collection, the specific number should not, as long as we control for household size. However, given that women are more likely to interact with other women in the village, particularly around trust-building events, such as child-rearing, having more women in the house may induce more trust. Last, somewhat intuitively, we find that those villages with a higher variance in housing assets had lower levels of trust. We choose housing assets since these assets are usually highly visible to fellow villagers. If there is a sense in the village that some are obviously much wealthier than others, this disparity may arguably erode trust.

For bridging social capital we use instruments meant to capture the ease of access to outside work. Thus, we use the household registration system to identify those members who can legally work off-farm and thus have greater legal freedom of movement, which proves to be highly-significant in explaining the percent of days household members work outside the township. Second, we find that the larger the household overall, the higher the percent working outside the township. Last, we find that having more pre-school age children decreases the probability that household members work far away from home. Again, we find none of these factors affect firewood collection.

When we use these instruments, we find similar qualitative results as before, in that both types of social capital reduce collection of firewood on public lands in the absence of other social capital, but that the two types of social capital appear to act as substitutes for each other, each decreasing the effect of the other when social capital is high.

Other results indicate that villagers are sensitive to how much firewood their neighbours collect on public lands, tending to increase their consumption alongside their fellow villagers. We also observe that the more costly and less abundant wood is from their private lands, the more villagers tend to collect from public lands. Last, income, as proxied by household expenditure on non-fuel goods, appears to be negatively correlated with firewood collection, implying that firewood is likely an inferior good.

In conclusion, we find that when considering a village's ability to successfully manage a common pool resource, one may need to consider both levels of bonding and bridging social capital. That is, the ability of strong levels of trust and social norms within the village to enforce resource use agreements appears to be affected by the strength of social networks outside the village.

Reference

Acheson, J. (2000). 'Varieties of institutional failures', Presented as the Keynote Address at "Constituting the Commons: Crafting Sustainable Commons in the New Millennium", the Eighth Conference of the International Association for the Study of Common Property, Bloomington, Indiana, USA, May 31 - June 4, 2000, http://dlc.dlib.indiana.edu/archive/00000195/00/iascpkeynote.pdf.

Algan, Y. and Cahuc, P. (2010). 'Inherited trust and growth', *American Economic Review,* vol. **100**(5), pp.2060-92.

Anderson, S., Baland, J. and Moene, K.O. (2009). 'Enforcement in informal saving groups', *Journal of Development Economics,* vol. **90**(1), pp. 14-23.

Baylis, K. and Perloff, J. (2010). 'Trade Diversion from Tomato Suspension Agreements', *Canadian Journal of Economics*, vol. **43**(1), pp. 127-51.

Berkes, F. and Folke, C., eds., (1998). *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*, Boston: Cambridge University Press.

Bowles, S. and Gintis, H. (2002). 'Social capital and community governance', *Economic Journal*, vol. **112**(483), pp. 419-436.

Bramoullé, Y. and R. Kranton (2005). 'Strategic experimentation in networks', NajEcon Working Paper Reviews No. 784828000000000417, www.najecon.org.

—— (2007). 'Risk-sharing networks', *Journal of Economic Behavior and Organization,* vol. **64**(3-4), pp. 275-94.

Carter, M. and Maluccio, J. (2003). 'Social capital and coping with economic shocks: an analysis of stunting of South African children', *World Development*, vol. **31**(7), pp. 1146-63.

Conservation International (2007). *Biodiversity Hotspots*, http://www.biodiversityhotspots.org/xp/Hotspots/china/Pages/default.aspx.

Dayton-Johnson, J. (2000). 'Determinants of collective action on the local commons: a model with evidence from Mexico', *Journal of Development Economics*, vol. **62**(1), pp. 181-208.

De Weerdt, J. and Dercon, S. (2006). 'Risk-sharing networks and insurance against illness', *Journal of Development Economics*, vol. **81**(2), pp. 337-56.

Durlauf, S.N. and Fafchamps, M. (2005). 'Social capital', in (P. Aghion and S.N. Durlauf, eds), *Handbook of Economic Growth,* pp.1639-99, Amsterdam: Elsevier.

Durante, R. (2010). 'Risk, cooperation and the economic origins of social trust: an empirical investigation', Unpublished.

Easterly, W. and Levine, R. (1997). 'Africa's growth tragedy: policies and ethnic divisions', *Quarterly Journal of Economics*, vol. **112**(4), pp. 1203-50.

Fafchamps, M and Minten, B. (2002), 'Returns to social network capital among traders', *Oxford Economics Papers,* vol. **54**(2), pp. 173-206.

Gong, Y., Baylis, K., Xu, J., and Bull, G. (2010). 'Individual social interactions, village Institutions and rural villagers' mutual trust: survey and field experimental evidence from western rural China', Unpublished.

Hardin, G. (1968). 'The tragedy of the commons', *Science*, vol. **162**(13), pp. 1243-48.

Helliwell, J. (1996). 'Economic growth and social capital in Asia', in (R.G. Harris, eds), *The Asia Pacific Region in the Global Economy: A Canadian Perspective*, pp. 21-42, Calgary: University of Calgary Press.

Jensen, R. and Oster, E. (2008). 'The power of TV: cable television and women's status in India', *Quarterly Journal of Economics*, vol. **124**(3), pp. 1057-94.

Kähkönen, S. (1999). 'Does social capital matter in water and sanitation delivery? A review of literature', SCI Working Paper No. 9, Washington: World Bank.

Knack, S. and Keefer, P. (1997). "Does social capital have an economic payoff? A cross-country investigation', *Quarterly Journal of Economics*, vol. **112**(4), pp. 1251-88.

La Porta, R., Lopez-de-Silanes, F., Shleifer, A. and Vishny, R. (1997). 'Legal Determinants of External Finance', *Journal of Finance*, vol. **52**(3), pp. 1113-55.

McCarthy, N., Sadoulet, E. and Janvry, A. (2001). 'Common pool resource appropriation under costly cooperation', *Journal of Environmental Economics and Management*, vol. **42**(3), pp. 297-309.

Meinzen-Dick, R., Raju, K.V. and Gulati, A. (2002). 'What affects organization and collective action for managing resources? Evidence from canal irrigation systems in India', *World Development*, vol. **30**(4), pp. 649-66.

Narayan, D. (1999). 'Bonds and bridges: social capital and poverty', World Bank Policy

Research Working Paper 2167. Washington, D.C.: World Bank.

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge: Cambridge University Press.

—— (1992). *Crafting Institutions for Self-Governing Irrigation Systems*, San Francisco, California: ICS Press.

—— (1999). 'Coping with tragedies of the commons', *Annual Review of Political Science*, vol. **2**, pp. 493-535.

Palloni, A., Massey, D., Ceballos, M., Espinosa, K. and Spittel, M. (2001). 'Social capital and internal migration: A test using information on family networks', *American Journal of Sociology*, vol. 1**06**(5), 1262-98.

Putnam, R.D. (2000). *Bowling Alone: The Collapse and Revival of American Community*, New York: Simon & Schuster.

Schechter, L. (2007). 'Theft, gift-giving, and trustworthiness: honesty is its own reward in rural Paraguay', *American Economic Review*, vol. **97**(5), pp. 1560-82.

Su, Y., (2002). 'A case study from Yulong Village in Lijiang county's Baisha Township', in (Southwest China Forest Resources Conflict Management Case Study Research Group, eds), *Conflict and Conflict Management: A New Approach to Conflict Management in the Forests of Southwest China*, Beijing: People's Press.

Woolcock, M., (1998). 'Social capital and economic development: Toward a theoretical synthesis and policy framework', *Theory and Society*, vol. **27**, pp. 151-208.

Xu, J. and Wilkes, A. (2004). 'Biodiversity impact analysis in northwest Yunnan, southwest China', *Biodiversity and Conservation*, vol. **13**(5), 959-83.

Appendices

A Proof of Proposition 1

$$
\begin{aligned}
m_i &= \gamma\eta\sigma_\mu^2\left(1-M_i r_{iB}\right)\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right) r_A \\
&\quad -\frac{1}{2}\gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n\left(r_{nB}\right)^2+\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)^2\right)\left(r_A\right)^2 \\
&> \gamma\eta\sigma_\mu^2\left(1-M_i r_{iB}\right)\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right) r_A-\gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)^2\left(r_A\right)^2 \\
&= \gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\left(1-M_i r_{iB}-\left(N-1\right) r_A-\sum_{n\neq i}^{N} M_n r_A r_{nB}\right) r_A \\
&> 0.
\end{aligned}
$$

The first derivative of m_i with respect to A_i is:

$$
\begin{aligned}
\frac{\partial m_i}{\partial A_i} &= \gamma\eta\sigma_\mu^2\left(1-M_i r_{iB}\right)\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\frac{\partial r_A}{\partial A_i} \\
&\quad -\gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n\left(r_{nB}\right)^2+\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)^2\right) r_A\frac{\partial r_A}{\partial A_i} \\
&> \gamma\eta\sigma_\mu^2\left(1-M_i r_{iB}\right)\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\frac{\partial r_A}{\partial A_i} \\
&\quad -\gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\left(1+\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right) r_A\frac{\partial r_A}{\partial A_i} \\
&= \gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\left(1-M_i r_{iB}-N r_A-\sum_{n\neq i}^{N} M_n r_A r_{nB}\right)\frac{\partial r_A}{\partial A_i} \\
&= \gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\left(\theta_i-r_A\right)\frac{\partial r_A}{\partial A_i}.
\end{aligned}
\tag{A.1}
$$

Since $\frac{\partial r_A}{\partial A_i}>0$ and $\theta_i \geq r_A$, we then have $\frac{\partial m_i}{\partial A_i}>0$.

The first derivative of m_i with respect to B_i is:

$$
\frac{\partial m_i}{\partial B_i}=-\gamma\eta\sigma_\mu^2 M_i\left\{\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right\} r_A\frac{dr_{iB}}{dB_i}. \tag{A.2}
$$

Since $\frac{dr_{iB}}{dB_i}>0$, we then have $\frac{\partial m_i}{\partial B_i}<0$.

Taking the first derivative of $\frac{\partial m_i}{\partial A_i}$ with respect to B_i yields:

$$\frac{\partial^2 m_i}{\partial A_i \partial B_i} = -\gamma\eta\sigma_\mu^2 M_i \left\{ (N-1) + \sum_{n\neq i}^{N} M_n r_{nB} \right\} \frac{\partial r_A}{\partial A_i} \frac{dr_{iB}}{dB_i}. \quad \text{(A.3)}$$

Since $\frac{\partial r_A}{\partial A_i} > 0$ and $\frac{dr_{iB}}{dB_i} > 0$, we thus have $\frac{\partial^2 m_i}{\partial A_i \partial B_i} < 0$.

B Proof of Proposition 2

Substituting (8) and (9) into the group objective function, we then have

$$\max_{\{\hat{c}_1,\hat{c}_2,\cdots,\hat{c}_N\}} \sum_{i=1}^{N} \left(\left(1+\frac{1}{\alpha m_i}\right) u\left(\hat{c}_i,\hat{c}_{-i}\right) - \frac{1}{\alpha m_i} u\left(c_i\left(\hat{c}_{-i}\right),\hat{c}_{-i}\right) \right)$$

$$= \max_{\{\hat{c}_1,\hat{c}_2,\cdots,\hat{c}_N\}} b\sum_{i=1}^{N} \left(\left(1+\frac{1}{\alpha m_i}\right)\hat{c}_i \left(\frac{a-d}{b} - \sum_{n=1}^{N}\hat{c}_n\right) - \frac{1}{4\alpha m_i}\left(\frac{a-d}{b} - \sum_{n\neq i}^{N}\hat{c}_n\right)^2 \right)$$

The first order condition for user $i = 1,2,\cdots,N$ is given by:

$$\left(1+\frac{1}{2\alpha m_i}+\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{1}{m_n}\right)\left(\frac{a-d}{b}-\sum_{n=1}^{N}\hat{c}_n\right) - \frac{1}{2\alpha}\sum_{n=1}^{N}\frac{\hat{c}_n}{m_n} - \sum_{n=1}^{N}\hat{c}_n - \frac{1}{2\alpha}\frac{\hat{c}_i}{m_i} = 0. \quad \text{(B.1)}$$

Summation of all the users' first order condition yields:

$$\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{\hat{c}_n}{m_n} = -\left(\frac{2N}{N+1}+\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{1}{m_n}\right)\sum_{n=1}^{N}\hat{c}_n + \left(\frac{N}{N+1}+\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{1}{m_n}\right)\left(\frac{a-d}{b}\right). \quad \text{(B.2)}$$

Substituting (B.2) into (B.1) to eliminate $\sum_{k=1}^{N}\frac{\hat{c}_k}{m_k}$ and rearranging yields:

$$\hat{c}_i = -\left(\frac{4\alpha}{(N+1)}m_i + 1\right)\sum_{n=1}^{N}\hat{c}_n + \left(\frac{2\alpha}{(N+1)}m_i + 1\right)\frac{a-d}{b}. \quad \text{(B.3)}$$

Summation over i on both sides and rearranging solves the total cooperative consumption:

$$\sum_{n=1}^{N}\hat{c}_n = \frac{2\alpha\sum_{n=1}^{N}m_n + N(N+1)}{4\alpha\sum_{n=1}^{N}m_n + (N+1)^2}\frac{a-d}{b}. \quad \text{(B.4)}$$

Substituting (B.4) into (B.3) solves user *i*'s optimal consumption under cooperative strategy:

$$\hat{c}_i = \frac{2\alpha\left(\sum_{n=1}^{N} m_n - (N-1)m_i\right) + (N+1)}{4\alpha\sum_{n=1}^{N} m_n + (N+1)^2}\frac{a-d}{b}. \tag{B.5}$$

Now we need to show whether condition in (15) is satisfied. Substituting $\sum_{n=1}^{N}\hat{c}_n$ in (B.4) and $\hat{c}_i$ in (B.3) into $\hat{U}_i = \frac{b(1+\alpha m_i)}{\alpha m_i}\hat{c}_i\left(\frac{a-d}{b} - \sum_{n=1}^{N}\hat{c}_n\right) - \frac{b}{4\alpha m_i}\left(\frac{a-d}{b} - \sum_{n\neq i}^{N}\hat{c}_n\right)^2$ and rearranging yields the user *i*'s utility of consuming the CPR under cooperative strategy:

$$\hat{U}_i = \frac{\left(2\alpha\sum_{n=1}^{N} m_n + (N+1)\right)^2 - \left(4\alpha\sum_{n=1}^{N} m_n + (3N-1)\right)(N-1)\alpha m_i}{\left(4\alpha\sum_{n=1}^{N} m_n + (N+1)^2\right)^2}\frac{(a-d)^2}{b}. \tag{B.6}$$

User *i*'s utility of consuming the CPR under non-cooperative strategy is given by (3) and (5):

$$\tilde{U}_i = \frac{1}{(N+1)^2}\frac{(a-d)^2}{b}. \tag{B.7}$$

To make the cooperative equilibrium enforceable, we must have $\hat{U}_i \geq \tilde{U}_i$ for each $i = 1, 2, \cdots, N.$ Using the expressions in (B.6) and (B.7) we then have:

$$m_i \leq \frac{N(N+3)}{(N+1)^2}\bar{m} + \frac{N(N-1)(3N+5)}{(N+1)^2\left(4N\alpha + (N+3)/\bar{m}\right)} \quad for\ \forall\ i = 1, 2, \cdots, N, \tag{B.8}$$

in which $\bar{m} = \frac{1}{N}\sum_{n=1}^{N} m_n$. (B.5) is equivalent to:

$$\max_{\{j=1,2,\cdots,N\}}(m_j) \leq f(\bar{m}), \tag{B.9}$$

in which $f(\bar{m}) \leq \frac{N(N+3)}{(N+1)^2}\bar{m} + \frac{N(N-1)(3N+5)}{(N+1)^2\left(4N\alpha + (N+3)/\bar{m}\right)}$.

Now we explore the relationship between the optimal consumption under cooperative strategy and the vulnerability to social sanction. Using the expression of $\hat{c}_i$ in (B.5), we can derive the first derivative of $\hat{c}_i$ with respect to m_i:

$$\frac{d\hat{c}_i}{dm_i} = -\frac{2(N-1)\left(4\sum_{n\neq i}^{N} m_n + N(N+1)\right)}{\left(4\sum_{n=1}^{N} m_n + (N+1)^2\right)^2}\frac{a-d}{b} < 0 . \tag{B.10}$$

The second derivative of $\hat{c}_i$ with respect to m_i is:

$$\frac{d^2\hat{c}_i}{d(m_i)^2} = \frac{16(N-1)\left(4\sum_{n\neq i}^{N} m_n + N(N+1)\right)}{\left(4\sum_{n=1}^{N} m_n + (N+1)^2\right)^3}\frac{a-d}{b} > 0 . \tag{B.11}$$

C Proof of Proposition 3

Combining $\frac{d\hat{c}_i}{dm_i} < 0$ and $\frac{\partial m_i}{\partial A_i} > 0$, we then have $\frac{\partial \hat{c}_i}{\partial A_i} = \frac{d\hat{c}_i}{dm_i}\frac{\partial m_i}{\partial A_i} < 0$.

Combining $\frac{d\hat{c}_i}{dm_i} < 0$ and $\frac{\partial m_i}{\partial B_i} < 0$, we then have $\frac{\partial \hat{c}_i}{\partial B_i} = \frac{d\hat{c}_i}{dm_i}\frac{\partial m_i}{\partial B_i} > 0$.

Taking partial derivative of $\frac{\partial \hat{c}_i}{\partial A_i}$ with respect to B_i yields:

$$\frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} = \frac{d^2\hat{c}_i}{d(m_i)^2}\frac{\partial m_i}{\partial B_i}\frac{\partial m_i}{\partial A_i} + \frac{d\hat{c}_i}{dm_i}\frac{\partial^2 m_i}{\partial A_i \partial B_i} . \tag{B.12}$$

Substituting $\frac{d^2\hat{c}_i}{d(m_i)^2}$ in (B.11), $\frac{\partial m_i}{\partial B_i}$ in (B.2), $\frac{\partial m_i}{\partial A_i}$ in (B.1), $\frac{d\hat{c}_i}{dm_i}$ in (B.10), and $\frac{\partial^2 m_i}{\partial A_i \partial B_i}$ in (B.3) into (B.12) and rearranging yields:

$$
\begin{aligned}
\frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} &= 4\rho_i \sum_{n=1}^{N} m_n + \rho_i \left(N+1\right)^2 \\
&\quad - 8\rho_i \gamma\eta\sigma_\mu^2 r_A \left\{ \begin{array}{l} \left(1 - M_i r_{iB}\right)\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB} \right) \\ - \left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n \left(r_{nB}\right)^2 + \left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB} \right)^2 \right) r_A \end{array} \right\} \\
&= 4\rho_i \left(\sum_{n=1}^{N} m_n - 2m_i \right) + \rho_i \left(N+1\right)^2 \\
&\quad + 4\rho_i \gamma\eta\sigma_\mu^2 \left(r_A\right)^2 \left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n \left(r_{nB}\right)^2 + \left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB} \right)^2 \right) \\
&> 0,
\end{aligned}
$$

where

$$
\rho_i \equiv \frac{2\gamma\eta\sigma_\mu^2 \left(N-1\right) M_i \left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB} \right) \left(4\sum_{n\neq i}^{N} m_n + N\left(N+1\right) \right) \frac{a-d}{b} \frac{\partial r_A}{\partial A_i} \frac{dr_{iB}}{dB_i}}{\left(4\sum_{n=1}^{N} m_n + \left(N+1\right)^2 \right)^3}.
$$

D Proof of Proposition 4

Taking the partial derivative of $\hat{c}_i$ in (20) with respect to A_i yields:

$$
\frac{\partial \hat{c}_i}{\partial A_i} = \frac{1}{\beta} \left(\left(N-1\right) + \left(M-1\right) \sum_{n\neq i}^{N} r_{nB} \right) \hat{\mu}_i \frac{\partial r_A}{\partial A_i} < 0,
$$

Taking the partial derivative of $\hat{c}_i$ in (20) with respect to B_i yields:

$$
\frac{\partial \hat{c}_i}{\partial B_i} = \frac{1}{\beta} \left(M-1\right) \hat{\mu}_i \frac{dr_{iB}}{dB_i} < 0,
$$

Taking the partial derivative of $\frac{\partial \hat{c}_i}{\partial A_i}$ with respect to B_i yields:

$$
\frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} = 0.
$$